Case Study of Tacit Knowledge Sharing in a Distributed Design Studio

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Abstract

This paper demonstrates the effects of experts' tacit knowledge on improving architectural students' design artifacts in a distributed design studio. In geographically distributed design environments, the Internet is an important medium by which architects can share tacit knowledge in the form of dialogue via online communication technologies, such as online chat and Instant Messaging (IM). In spring 2003, the National Aeronautics and Space Administration (NASA) and 8 schools conducted a collaborative design studio to develop a crew restraint system for space flights. Online chat software was used as a primary communication channel. Throughout the entire design studio, NASA professionals served as knowledge holders while undergraduate students participated as knowledge seekers. An interpretive content analysis and case study methodology were used in this study. We qualitatively observed the interactions between NASA and the students based upon two aspects: knowledge reflection and design improvement. Data were collected using document analysis of all knowledge sources and students' design artifacts. The findings of this study indicate that the online chat system is useful in sharing tacit knowledge for the early part of design processes in a distributed design environment. Experts' tacit knowledge appears to not only influence how students understand problems, but how they initiate conceptual design. This study provides empirical evidence regarding tacit knowledge sharing, and strengthens Schon's (1983) claim about knowledge reflection in design studio. Furthermore, this study introduces architectural practitioners to the practical necessity of tacit knowledge sharing. This study is significant because its findings indicate the appropriate knowledge management strategy for architectural practitioners.

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1 INTRODUCTION

Human knowledge can be simply classified into two types: tacit and explicit. According to several literatures, tacit knowledge is highly personal (Polanyi 1966), implicit (Reber 1991), context-specific (Sternberg 1994) knowledge housed in the human brain, such as expertise, skill, understanding, or professional insight formed as a result of experience. Tacit knowledge has tremendous value when made available to the right people at the right time.

However, several researchers point out that tacit knowledge is hard to formalize, write down, and communicate (Nonaka 1995) because it is deeply embedded in employees or organizations. However, there is a range of different degrees of tacit knowledge as shown in Figure 1. Ambrosini and Bowman (2001) point out that deeply ingrained tacit knowledge (Type A) is not accessible by the use of languages or codes. Highly tacit knowledge could be only accessed using physical meeting, demonstration, or learn-by-doing (Schon 1983), strategies requiring the physical presence of knowledge holders. In this study, tacit knowledge sharing is subsequently limited to Type B Knowledge (imperfectly articulated tacit skills) and Type C Knowledge (articulated tacit skills) (see Figure 1).

In geographically distributed virtual design environments, the Internet provides an important medium by which architects can share their tacit knowledge in the form of dialogue. The primary communication channels for online tacit knowledge sharing are typically an online chat system or instant messaging (Ribak 2002). Although the functionality of these two tools is widely adopted for entertainment purposes, several articles (Isaacs et al. 2002, Ribak 2002) report cases where these tools successfully support knowledge sharing and informal communications in a large firm.

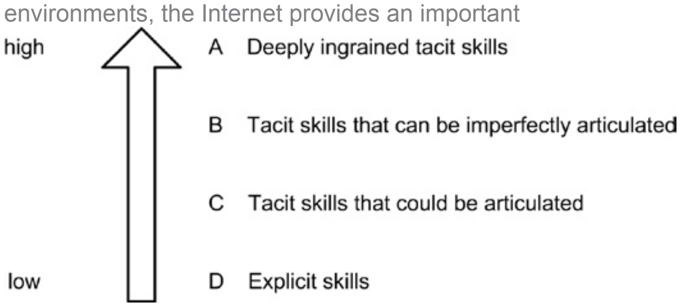

Figure 1. Degree of Tacit Knowledge (Ambrosini and Bowman 2001)

Novice architects gain tacit knowledge through real experience or receiving instructions, and begin to extend the web of knowledge in the architectural domain. Although Donald Schon (1983) convincingly demonstrated that experts' tacit knowledge is a significant resource in the architectural profession, architectural practitioners continue to concentrate on explicit knowledge management, driven by exponential advances in Information Technology (IT) solutions, which make knowledge explicit and store it as computer software and databases. Although tacit knowledge is important to success, architects grant little recognition to it. The literature (Hansen et al. 1999, Johannessen et al. 2001) indicates that IT-based solutions only allow people to search for and retrieve only explicit knowledge. Therefore, the emphasis on IT may reduce the attention to tacit knowledge; consequently, experts' tacit knowledge could be wasted and ignored.

Several researchers in the field of architecture have emphasized the importance of tacit knowledge sharing in architectural design environments. Schon (1983) explored the traditions of the architectural studio to investigate how architectural students learn from instructors in a design studio. He observed the learning process of architectural design in a studio setting from the beginning of the semester to the final review. Through in-depth description, he found two forms of the learning process: learn-by-doing and reflection-in-action. In a design studio setting, instructors usually tell and demonstrate what they want to show, and students listen and imitate that. As a result, Schon points out that tacit knowledge is the primary mechanism for sharing expertise from the experienced designer. In addition, Cross (1995) concludes that the collaborative process significantly influences the quality of design.

Huang (1999) also studied knowledge sharing in distributed design environments. Throughout 60 interviews and observations of designers involved in collaborative efforts, he analyzed the collaboration patterns among design participants and derived how these patterns change with the introduction of new collaborative media. One of the significant findings from his research is the relationship between knowledge sharing and innovative design. Consequently, he insists that knowledge required to make sound design decisions should be distributed and leveraged within organizational boundaries. He concludes that such sharing contributes to innovative design solutions, and the actions of participants are more transparent and shared, while the systems may reduce the costs of knowledge transfer. A distributed design studio initiated by NASA led us to conduct this study based on the same research inquiry of the studies noted above. Several design studies have been conducted

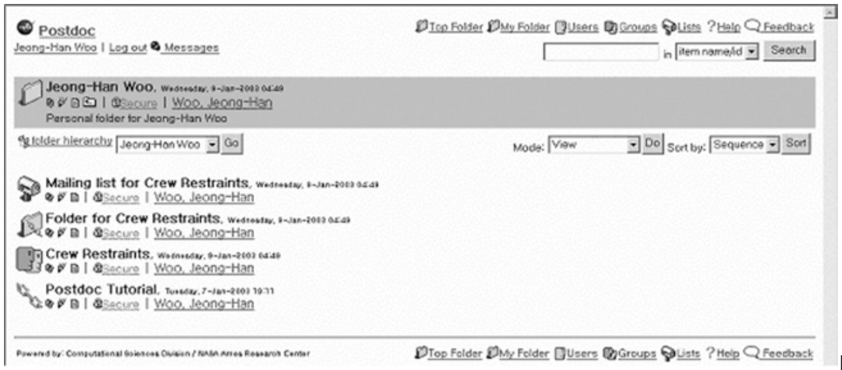

Figure 2. Screen Shot of PostDoc Main Page

concerning collaborative media in the architectural profession. However, these studies rarely focus on the impact of tacit knowledge on the design artifact. This unexplored topic of the design studio enabled us to clearly observe the effect of knowledge reflections on the students' design artifacts. We qualitatively observed the improvements of students' design performance in a design studio setting based upon two aspects: knowledge reflection and design improvement. The qualitative content analysis was conducted on all dialogue records, documentations provided by NASA and students' design artifacts. This study is significant because its findings guide the development of an appropriate knowledge management strategy for architectural practitioners.

2 METHODS

2.1 Distributed Design Studio with NASA Context

The design studio was conducted during the 2003 spring semester. NASA initiated a distributed design studio to develop requirements, guidelines, and conceptual designs for an ergonomic crew restraint system. The agency is interested in benefiting from the creativity and ingenuity of undergraduate students while providing them with a challenging subject for a class project. NASA final deliverables include:

- Development of functional requirements
- Design concept prototype development
- Computer modeling evaluations of concepts
- Microgravity evaluation
- Implementation plan.

Participant

The design studio was led by four NASA design professionals. Approximately seventy undergraduate students and ten faculty members from eight schools were invited to this design studio. All undergraduate students are naïve designers in terms of design experiences, representing multiple design disciplines and approaches such as architecture, mechanical engineering, industrial engineering, and human engineering. However, it does not matter how the students design, so long as they concentrate on all design activities in producing the final description of the proposed work according to the instructions from NASA.

Knowledge Sharing

Since no school has experience in crew restraint systems design, NASA staff members exclusively provided knowledge resources about these systems. At the beginning of the studio, the agency provided a set of documentations containing extensive data, information and knowledge about crew restraint systems in the form of video, written document and photographs. As explicit knowledge, the documents provide details of the requirements already developed, lessons learned, and information about existing designs. The documentation was previously used to develop preliminary operational and functional design requirements for a multi-purpose crew restraint system. Additional documentation was provided upon request. Students used the documents as the manual for proposed design concepts. The documents were posted and accessible through the password-protected web site called PostDoc (https://postdoc.arc.nasa.gov) as shown in Figure 2. While all knowledge resources were posted on PostDoc, each school held physical face-to-face meetings with their course instructors.
In addition to the accessible documentation, three NASA professionals shared their tacit knowledge by actively communicating with students using an online chat system (http://www.nsbri.org/Chat/hhfo/). Throughout chat sessions, students held reflective conversations with NASA staff, who scheduled the chat sessions. The first chat session was conducted from 2:00 P.M. to 5:00 P.M.on February 5, 2003: seventeen people from five different schools and NASA participated, generating 170 messages. The second chat session was conducted from 2:00 P.M. to 4:00 P.M. on February 6, 2003: thirteen people from four different schools and NASA participated, and 107 messages were generated. All dialogue was captured and posted on PostDoc.

Online Chat

The chat system used was typical chat software providing login awareness of the system users, and supporting one-to-one communication. All dialogues were saved as natural conversations and made accessible for students to review for sharing ideas and expertise in the dialogue. The chat sessions opened with a brief welcome from NASA staff. Students then asked questions about crew restraints system. Each message varied in length. Since the chat sessions were held exclusively for the project, all messages related to the restraint design. Some messages contained relatively long explanations of the situations with the international space shuttle. Since only three NASA professionals answered all questions from the students, the answers were often delayed.

Overall Design Processes

The design studio was initiated with a telephone conference between NASA and all school participants at the beginning of the 2003 spring semester. NASA staff and studio participants held numerous online chat sessions and telephone meetings throughout the project. At the end of the semester, the students submitted their final design presentations.

After sharing extensive knowledge, the students developed their preliminary conceptual designs for a critique, utilizing a video conference.To refine their designs for the next step, students received consultations from NASA staff via chat sessions and from their own instructors in the local design studio. After getting the correct design directions, the students conducted the remainder of thier project primarily with the instructors.

NASA staff reviewed the final designs and ranked them within each university, evaluating whether or not each project met enough of the requirements and showed enough feasibility to pursue. After posting the final project on the Web site, the design studio was completed.

3 Data Collection

Data sources include knowledge resources provided by NASA and students' design artifacts. Data for this study were downloaded from the PostDoc website hosted by NASA.

3.1 Tacit Knowledge Sources

NASA provided six different tacit knowledge resources via the Web site as shown in Figure 3. The primary tacit knowledge resources were chat transcripts captured by NASA staff and posted on PostDoc. "Preliminary Focus Group Findings" refers to the summary of a series of meetings held to discuss lessons learned from "Restraints and Mobility Aids" (R&MA) and solicit ideas and concepts for restraints. Other tacit knowledge resources were the summary of comments from design professionals.

File Name	Format	Description
Preliminary Focus Group Findings	MS Word	Preliminary Focus Groups Meetings were held and findings were summarized.
Chat sessions	MS Word	Compiled questions and answers.
LSG Question and Answer	MS Word	Life Science Glove box Question and Answers dealing with hardware details of configurations.
Compiled Crew Restraint Comments	MS Word	Database of Crew Debrief comments on individual restraints (pros/cons).
Restraint Summit Comments	MS Word	Restraint Summit Meeting Summary Notes were compiled with crew comments of restraint systems currently on ISS.
Question and Answer Session Feb 21	MS PowerPoint	Presentation covering all the questions posed by participating universities.

Figure 3. Tacit Knowledge Sources

3.2 Explicit Knowledge Resources

Explicit knowledge resources were also posted on PostDoc, as shown in Figure 5. The contents of explicit knowledge resources mostly cover all disciplines and guidelines of restraint systems design. Conversely, the contents of tacit knowledge resources and supplement explicit knowledge were exclusively based on expertise.

4 Data Analysis

Ethnographical study conducted by Schon (1985) and Cross (2001) is most relevant to the data analysis of this study. Their studies show that detailed observation enables systematic descriptions of designers' improvement followed by experts' instruction. Likewise, the main task of data analysis is to qualitatively observe the improvements of students' design performance as "reflection-in-action" (Schon 1983) in a design studio setting. While thoroughly searching for students' knowledge reflection, this research qualitatively describes the improvements of students' design performance.

The first step entailed reading the online chat transcripts. Those for one-to-one conversations were not included in this study, since the majority of the contents were simple clarifications of the discussion. To investigate what people discussed in the chat sessions, we conducted qualitative content analysis on the two chat session transcripts.The content of online dialogue comprises messages between NASA professionals and groups of students and faculty. The dialogue occurred as students' questioned NASA staff about problems, and presented ideas for resolving the problems. During the reading, the problems were unsystematically grouped into categories as follows:

- Comfort/Injury
- Foot Restraints
- Body Restraints
- Handrails
- Maintenance

There were no restrictions about what might count as a problem category. We simply summarized themes that emerged with repeated reading. Next, the students' design artifacts were thoroughly investigated.

5 Findings

Cross (2000) introduces French's (1985) model of the design process based on the following activities: analysis of problem,conceptual design, embodiment of schemes,detailing. Qualitative analysis of dialogues and design artifacts resulted in observations about knowledge reflection in design artifacts in the following aspects:

- Tacit knowledge sharing
- Analysis of problem
- Conceptual design
- Feedback
- Works from non-participants

5.1 Tacit knowledge sharing

Three NASA staff members actively participated as knowledge holders in the online chat sessions. Their previous experience with restraint systems design made it possible for students to identify a problem about which only an expert might be aware. Furthermore, this process helped students comprehend the significance of tacit knowledge sharing, in addition to the understanding of how dialogues during the early stages of design can assist NASA staff and the students themselves. There were several dialogues such as:

<Student 1> *Are these chat sessions set up for the various schools to share ideas as well?*

<NASA 1> *Certainly, you can use these sessions to share ideas as well.*

<Student 2> *Will the chat session be held routinely?*

<NASA 2> *In regards to CHAT session times, we will try to hold them routinely if necessary. But for this week it will only be today (now until 5 pm Central) and tomorrow 2 - 4 central time.*

The participants definitely wanted to talk with other team members via chat sessions to share ideas and experiences. A complex and unique project like this, amplifies the importance of tacit knowledge sharing. Increasingly, the students expected to face situations in which their previous knowledge would no longer be sufficient to complete a good design project, since the knowledge needs in this studio are dynamic and complicated. Therefore, experts' tacit knowledge should be shared to achieve better quality on design projects.

<Student 3> *Any chance of getting complete transcripts of both chat sessions, say, on post-doc?*

< NASA 1> *Yes, we will be sending out the complete transcripts of both chat sessions.*

< Student 4> *The summary of chat session yesterday organized by topic was really useful. Thanks.*

< Student 3> *Thank you so much, Rosie and Mihriban! Super-helpful chat.*

< NASA 1> *I believe there is another Chat at 4 pm Central. I think this is our cue.*

This series of dialogue indicates the successful conversion of tacit knowledge to explicit knowledge. In this dialogue, the participants definitely shared significant tacit knowledge about the project. NASA professionals offered numerous professional recommendations, intuitive expectations, and their experiences on other crew restraint design projects. The students knew that they could not receive such advice from explicit knowledge sources currently in existence. Because of past experiences, NASA professionals can share what must be undertaken at any given point. However, conventional tacit knowledge sharing requires physical face-to-face meeting (Nonaka 1995).

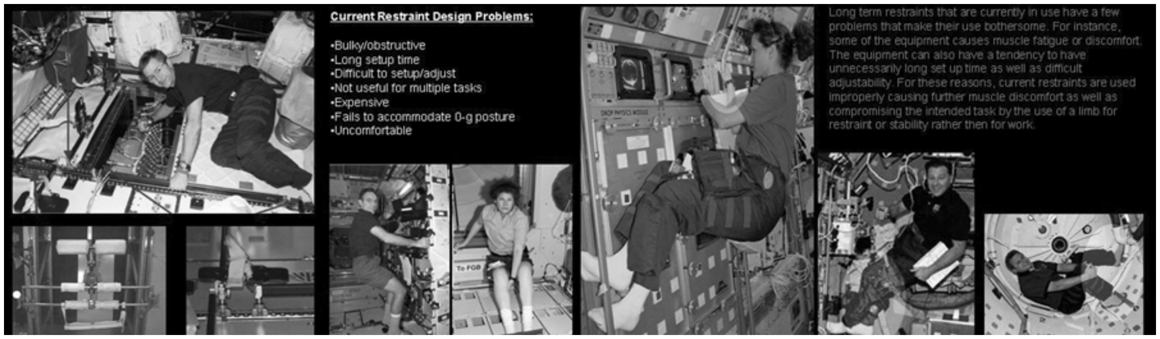

Figure 4. Design Example 1

In a distributed design studio, the need exists to share tacit knowledge at remote locations, such as different buildings or different offices, and receive immediate help. The online discussions addressed the same topics that could be discussed in the meeting room. It is less dynamic than face-to-face meetings, yet more dynamic than written messages alone.

5.2 Analysis of Problem

The findings of this study show that for analysis of problem experts' tacit knowledge is more informative than explicit knowledge. At the first stage of the design studio, all students thoroughly studied provided documentation broadly covering all aspects of crew restraints design, including design guidelines, manuals, technical specifications, and graphic samples. However, those materials were limited in use for the analysis of problem. Therefore, through the chat sessions, the students asked about problems they encountered. Cross (2000) says "the very first conceptualizations and representations of problem and solution are critical to the kinds of searches and other procedures that will follow, and so to the final solution that will be designed." A significant portion of the online chats was devoted to the clarification or explanation of real problems, and the majority of the problems were identified in the chat sessions. The discussions focused on important questions such as:

- Have existing restraint systems caused muscle injuries?
- Have the foot loops been useful in any particular task?
- Do the LSG arm holes restrain the upper body?
- Do astronauts want their feet restrained completely, or would they prefer more flexibility?

NASA answers for these questions formed the most concrete evidence of the problem and were part of the problem statement of each design project. Quickly, the students identified particular problems that would influence their approach to developing a conceptual design. Many problems were also clarified through the online chat sessions. The students could easily catch a well-defined problem, and then focus their work on one of those problems.

During online chat dialogues, one student opened up a new question about discomfort caused from current restraints. The following dialogue examples demonstrate typical conversations influencing the design. NASA staff was also able to provide information from previous experience.

<Student 5> *Have there been muscle injuries due to existing restraint systems?*

<NASA 1> *We didn't have any serious muscle issues but some discomfort reported. Use of handrails as a foot restraint caused some discomfort on the toe knuckles.*

The first problem the students encountered was the use of handrails as a foot restraint. Based on this problem, some of the students offered proposals to handle this problem as shown in Figure 4.

The second problem students encountered was complaints about the foot loops.

<Student 6> *There have been numerous complaints about the foot loops. Have the foot loops been useful in any particular task?*

<NASA 1> *Foot Loops - 1. Adjustment mechanism is not effective and comes loose 2. Collapsible so not easy to get in 3. Footplate is slippery with socks so they curl toes to restrain*

<Student 7> *Can any spring loaded mechanisms be utilized in the restraint designs?*

<NASA 1> *As long as it is simple, spring loaded mechanisms can be utilized. Based on above dialogue, a student generated the following design proposal (See Figure 5):*

The third problem was storing and maintaining the restraint systems.

<Student 8> How much space is devoted to storing restraints on-board the ISS?

<NASA>

<NASA> *Long term and temporary stowage config. for restraint are critical. There isn't any set dimensions. However, for temp. stowage, the config should be out of the aisle as much as possible with minimal interference with its surroundings. Also, it should be easily temp stowed. We can provide dimensions for the stowage containers.*

<Student 9> *Are current RMAs considered adequate for multiple rack translation and maintenance, including the tilt-out procedure?*

<NASA> *In regards to your question of current RMAs for multiple rack translation and maintenance.....Crew can do the work but is not sufficient for safety and not ideal. Current RMAs do not completely assist adequately for all tasks. Did I answer your question?*

The fourth problem is long set-up time and difficult adjustability. A student writes a problem statement as follows (See Figure 6):

“Long term restraints that are currently in use have a few problems that make their use bothersome. For instance, some of the equipment causes muscle fatigue or discomfort. The equipment can also have a tendency to have unnecessarily long set up time as well as difficult adjustability. For these reasons, current restraints are used improperly causing further muscle discomfort as well as compromising the intended task by the use of a limb for restraint or stability rather then for work.”
In the dialogue, NASA staff said that the handrails are the most effective system onboard ISS. A NASA staff member said:

“To add on to it, the only one that has been reported to be the most effective one onboard ISS thus far is the handrails. Quick note that there are plenty of them onboard thus they don’t need to move or remove it.”

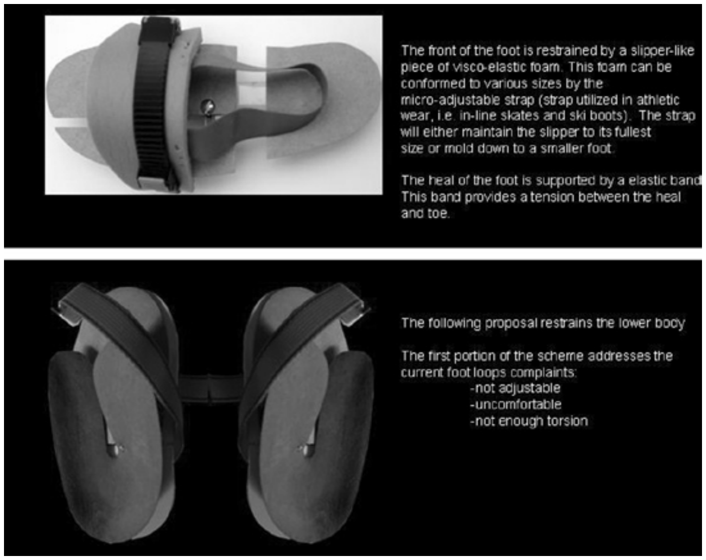

Figure 5. Design Example 2

<Student 10> *What are the size/weight constraints and envelope dimensions of the crew restraint?*

<NASA> *There isn’t any specified in any documentation. But, due to the upmess, both size and weight should be minimized as much as possible.*

< Student 11> *Is there an IVA specific document for design requirements, as in NASA STD-3000?*

< NASA> *Yes, SSP 50005 is for the vehicle human factors requirements and SSP 57000 is for the payloads human factors requirements. We can try to have them available on postDoc (at least the relevant sections),*

<Student 12> *Rosie - referring to the anthropometrics data, we wanted to know if there is a required range of height, weight, and size for an astronaut?*

<Student 13> *Check the NASA “how to become an astronaut” page on spaceflight.nasa.gov for height requirements*

< NASA> *The SSP 50005 reference document will have that anthropometrics information (at least it will be one of the relevant chapters we will include).*

< Student 1> *Thank you Mihriban.*

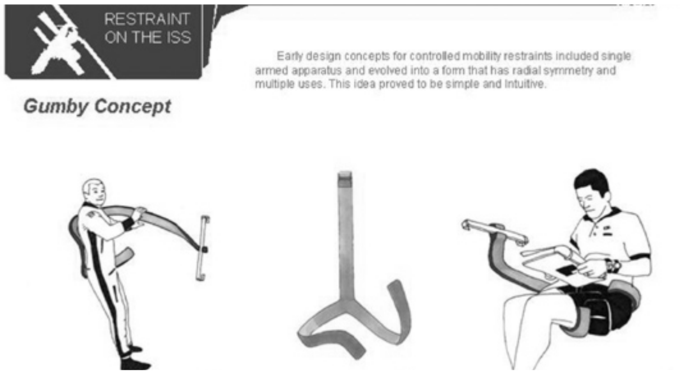

Figure 6. Design Example 3

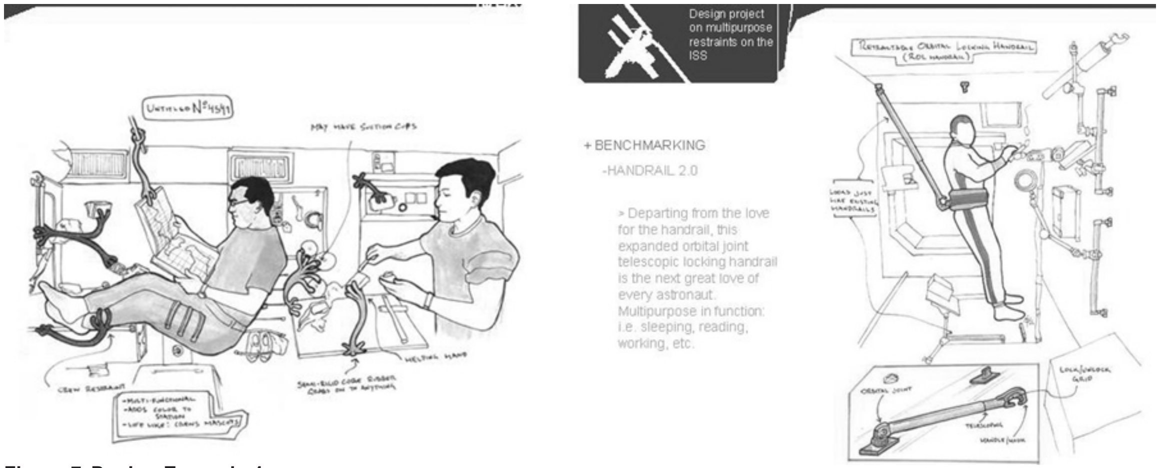

Figure 7. Design Example 4

The scientific approaches from engineering backgrounds appear to be too realistic to develop a creative and innovative design. So, NASA staff suggested that students ignore engineering data and concentrate on issues of stability, comfort, ease of use, and ease of installation.

<Student 14> *Are the handrail and seat track a vendor item? Can we obtain samples or detailed engineering drawings of these parts? Is seat track still to spec MS33601?*

<NASA> *Jason--yes, the seat track that we use is made primarily by Boeing (although some international partners get seat track elsewhere). I do not know of a capability to get a sample.*

<NASA> *I'm not familiar with MS33601....is this a military spec? For the purpose of this project, we are looking for CONCEPTUAL designs, so the details of the seat track are not particularly critical*

<Student 14> *Thanks Susan*

<Student 15> *I know there is a Generic Design Requirements Document (GDRD) for EVA, is there one for IVA?*

<NASA> *I believe there is a requirement document for IVA equipment design, but for the purpose of this project it is not necessary for CONCEPTUAL designs. Does this answer your question?*

<Student 15> *Yes, thank you*

<Student 16> *Astronaut Anthropometrics Data - Yes*

<NASA> *there is data available. For this project it will not be crucial to concept design....*

<Student 17> *Are there any significant material constraints, i.e. plastics, composites, etc.??*

<NASA> *We are not too concentrating on material constraints or exact measurements of restraint system but of concepts ideas that address issues of stability, comfort, ease of use, ease of installation.*

5.3 Works from non-participant schools

Only one school did not participate in the online chat sessions. Its students' approaches to recognizing problems, formulating concepts, and developing designs are markedly different from those of the other schools. The students from the non-participant school initiated their project by performing an extensive literature search and review. While the literature provides an impressive amount of information, there are limitations for understanding real problems for the crew restraints system. Design artifacts reflecting tacit knowledge are more likely to be complete, and thus more credible.

5.4 Feedback

The chat scripts are especially useful when they remind the participants of the topics discussed. Because of the volume of material, students might have difficulty in recalling all the conversations. If students have access to repositories containing such conversations, their works reflects experts' knowledge to a greater extent, and is more fruitful and competitive. To this end, a method for capturing knowledge should be developed. When professionals handle information of high value, they intuitively want to capture it, but they cannot spend time to capture and store in an appropriate place. When professionals leave an organization, knowledge also leaves. Therefore, systems should extract, reflect and retain experts' tacit knowledge within organizational boundaries before they leave. Processes to develop these systems in a working organization are heavily dependent upon the manager's business strategy. What is required is a manager who can imagine a more desirable future and invent ways of reaching it.

The final step of the study was to present its findings from this study to NASA professional staff members. Since this study included their dialogues, they could check the reliability of the data, as well as validate the instuctors' findings. The students did not participate in the validation process.

6 Conclusion

This study demonstrates the applicability of tacit knowledge sharing in a distributed design studio. We conducted a content analysis on three different types of media: tacit knowledge resources, explicit knowledge resources and students' design artifacts. It is difficult to separate the impact of tacit knowledge only and to determine which type of knowledge is more effective, since students typically develop projects based on both types of knowledge. However, we find that online chat dialogues contain exclusive tacit knowledge provided by NASA. Since NASA staff holds exclusive tacit knowledge of crew restraint systems, their answers or comments about the design work contained critical suggestions. The findings of this study show that students' design artifacts are practically improved by tacit knowledge sharing. Expert designers therefore appear to be a richer source of new ideas and alternative perspectives.

We have seen that the online chat system is useful in sharing tacit knowledge for the early part of design processes in a distributed design environment. It is apparent that tacit knowledge sharing generates a well-defined problem. The participants share their knowledge and reflect the solutions in action. Experts' tacit knowledge appears to not only influence how students understand problems, but how they start conceptual design. We believe this study provides empirical evidence regarding tacit knowledge sharing, and strengthens Schon's (1983) claim about knowledge reflection in design studio. Furthermore, the significance of this study introduces architectural practitioners to the practical necessity of tacit knowledge sharing. They must develop more effective ways to share employee's various levels of tacit knowledge. While deeply ingrained tacit knowledge may only be shared through learning by doing (Schon 1983), lower levels of tacit knowledge can be effectively articulated and shared by using Internet technology.

The essence of tacit knowledge sharing is a collaborative attitude and a willingness to collectively accomplish work and to jointly discover and develop the best solutions. This study suggests that a distributed design studio should be implemented based on the collaborative culture. A distributed design studio should consider cultural factors influencing knowledge sharing, trust and collaboration. Improving collaboration and cultural trust is one of the major tasks for effective knowledge management.

7 Future Study

This study was limited to qualitative research methods. To quantitatively analyze the impact of tacit knowledge on design artifacts, a questionnaire will be distributed to the participating students in the future. The final deliverable required by NASA was the conceptual designs. So, the results of this study are limited to partially showing the impact of tacit knowledge. In a future study, we will observe the impact of tacit knowledge on the entire design process.

Acknowledgement

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Reference:

Ambrosini, V., and C.Bowman, (2001). Tacit Knowledge: Some Suggestions for Operationalization, *Journal of management studies* 38(6): 811-829.
Cross, N., and A.C.Cross, (1995). Observations of teamwork and social processes in design, Design studies. 16:143-170.
Cross, N. (2000). *Engineering design methods*: *Strategies for product design*. 3rd ed. Wiley & Sons, UK.
Davenport, T., and L. Prusak, (1998). *Working knowledge: How organizations manage what they know*. Boston: Harvard Business School Press.
Dorst, K., and N.Cross, (2001). Creativity in the design process: Co-evolution of problem-solution. *Design studies*. 22(5):425-437.
Gero, J. S., and T.McNeill, (1998). An approach to the analysis of design protocols. Design studies, 19:21-61.
Hansen, M., N.Nohria, and T.Tierney, (1999). What is your strategy for managing knowledge? *Harvard business review*, 77(2): 106-18.
Huang, J. (1999). Knowledge haring and innovation in distributed design: Implications of internet-based media on design collaboration. *International journal for design computing*, DCNet '99.
Isaacs, E., A.Walendowski, S.Whittaker, D.Schiano, and C.Kamm, (2002). The character, functions, and styles of instant messaging in the workplace. *Proceedings of the CSCW'02,* 126-135. New Orleans, Louisiana.
Johannessen, J.A., J.Olaisen, & B.Olsen, (2001). Mismanagement of tacit knowledge: The importance of tacit knowledge, the danger of information technology, and what to do about it. *International journal of information management*, 21:3-20.
Nonaka, I., & H.Takeuchi, (1995). The *knowledge creating company*. New York: Oxford University Press.
Polanyi, M. (1966). *The tacit dimension*. Garden City: Doubleday.
Ribak, A., M.Jacovi, and V.Soraka, (2002). Ask before you search Peer Support and community building with ReachOut. *Proceedings of the CSCW'02*,126-135. New Orleans, Louisiana.
Reber, A. S. (1993). *Implicit learning and tacit knowledge: An essay on the cognitive unconscious*. New York: Oxford University Press.
Schon, D. (1983). *The reflective practitioner: How professionals think in action*. Basic Books, USA.
Schon, D. (1985). *Design studio*, London: RIBA Publications.
Sternberg, R. J., G.B.Forsythe,J.Hedlund, J.A.Horvath, R.K.Wagner, W.M. Williams, S.A. Snook, & E.L. Grigorenko, (2000). *Practical intelligence in everyday life.* New York: Cambridge University Press.